APPLICATION

FOR

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TITLE: PLASMA ETCHING UNIFORMITY CONTROL

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PLASMA ETCHING UNIFORMITY CONTROL

TECHNICAL FIELD

This invention relates to plasma etching uniformity control.

BACKGROUND

Plasma etching is used, e.g., in the fabrication of

5   integrated circuits to produce high-resolution patterns in a

semiconductor (e.g., silicon) wafer. The wafer is placed in a

chamber in which electrons are accelerated by radio frequency

(RF) or microwave electric fields. The electrons collide with

other molecules to produce ions, neutral radicals, and more

10   electrons. Between the plasma and the wafer surface layer, an

electron-free space-charge region, called a "sheath", is formed,

and ions are accelerated toward the wafer surface when entering

the sheath. The accelerated ions bombard the wafer surface with

high energies and chemically etch areas of the wafer that are

15   exposed to the plasma. The areas exposed are in patterns defined

by a resist placed on the wafer surface using lithographic

methods.

In a typical plasma etching process, the etch rate near the

center of the wafer is often greater than the etch rate in

20   peripheral regions of the wafer, which can lead to uneven etch

depths across the wafer. To alleviate this problem, wafers are

sometimes provided with a stop layer at the desired etch depth.

The stop layer is made of a material that is etched at a lower

rate compared to the wafer surface material. As a result, when

the central portions etch to the stop layer, etching can be continued until the peripheral regions etch to the stop layer.

DESCRIPTION OF DRAWINGS

FIG. 1A is a cross-sectional view of a plasma chamber.

5   FIG. 1B is a side view of a substrate.

FIG 2A is a graph of normalized etch rate as a function of position from substrate center.

FIG 2B is a graph of CF_3^* ion density as a function of distance from substrate center for one etch condition.

10   FIG 3A is a graph of normalized etch rate as a function of position from substrate center.

FIG 3B is a graph of SF_3^* and SF_5^* ion density as a function of distance from substrate center for one etch condition.

FIG 4 is a graph of normalized etch rates as a function of

15   position from substrate center for different etch conditions.

FIG 5A is a graph of distribution of ions and electrons in CF_4 plasma.

FIG 5B is a graph of distribution of ions and electrons in SF_6 plasma.

20   FIG 6 is a graph of normalized ion density as a function of position from substrate center.

Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

25   As will be described in more detail below, a plasma is generated from a gas having first and second components, and is

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used to etch a substrate material. The relative etch rate at one location on the substrate material to the etch rate at another location on the substrate material is controlled by selecting the amount of the first and second components in the gas.

5   Referring to Figs. 1A-1B, a system 100 for plasma etching includes a plasma reaction chamber 102 for generating a plasma 116 to etch a substrate 106 or material layers on substrate 106. Substrate 106 (patterned with a resist 119) may be, for example, a silicon wafer used to produce integrated circuits or a quartz

10   substrate for use as a lithography mask to define optical patterns on a photo-resist. System 100 includes a lower electrode 104 connected to a first radio frequency (RF) power supply 112. Lower electrode 104 serves as a pedestal for supporting substrate 106 within chamber 102. A ring-shaped dielectric pad 124 is

15   provided on top of lower electrode 104. Substrate 106 is placed on top of lower electrode 104 and surrounded by the ring-shaped dielectric pad 124. A second electrode 114 shaped as coils surrounding chamber 102 is connected to a second RF power supply 122. The wall of chamber 102 is connected to electric ground.

20   Dielectric liners 134 are placed on the inner walls of chamber 102.

A first etchant gas is introduced into a mixing chamber 126 through an inlet 108. The amount of the first etchant gas flowing into chamber 126 is regulated by a first mass flow controller

25   118. A second etchant gas is introduced into chamber 126 through an inlet 109. The amount of the second etchant gas flowing into chamber 102 is regulated by a second mass flow controller 120.

(Other gases, such as O_2, Ar, N_2, etc., typically in smaller amounts, may also be introduced into mixing chamber 126 through other inlets not shown in the figure.) The mixed gases flow from mixing chamber 126 to reaction chamber 102 through pipe 130 and

5   gas distribution channel 128. Channel 128 is a ring-shaped groove in the upper wall of reaction chamber 102 that allows gas to distribute evenly into reaction chamber 102. A vacuum pump 132 is connected to an outlet 110 at the bottom of chamber 102 to regulate the pressure inside chamber 102.

10   To generate a plasma, RF power is provided to the chamber by RF power supplies 112 and 122. First RF power supply 112 has a frequency of about 13.56 MHz, and second RF power supply 114 has a frequency of about 2 MHz (frequencies allowed by FCC). A suitable plasma chamber apparatus is available as model VRL-ME-

15   II-M-QTZ from Unaxis, St. Petersberg, Florida.

          Referring to Fig. 2A, a graph 202 shows etch rates at different locations on substrate 106 when CF_4 gas is used as the plasma gas. The conditions are as follows: the substrate 106 is a quartz wafer substrate, chamber pressure P = 22 mTorr, chamber

20   temperature = 72F, power of first RF power supply 112 is 150 watts, power of second RF power supply 122 is 300 watts, CF_4 = 60 sccm, and N_2 = 10 sccm. In graph 202, the black dots represent individual etch rates across the wafer at various distances measured from the center. Etch rate can be measured by using a

25   Lasertec phase measurement tool, model MPM-400, available from Lasertec USA Inc., San Jose, California.

Trend line 204, produced by the least-squares curve fitting method, is provided. Trend line 204 shows that with CF_4 gas supplied to chamber 102, the etch rate at a peripheral portion of substrate 106 is lower than the etch rate at the center. As an

5 example, the etch rate at a location 85 mm from the center is about 5% slower than the etch rate at the center. (Here, the results show variations of etch rate along radial directions from the center of wafer 102. It should be understood that the actual reference point is the center of lower plate 104, which is

10 situated at the center of chamber 102. The center of substrate 106 is used as the reference point since it is aligned with the center of lower plate 104.)

Referring to Fig. 3A, a graph 302 shows etch rates for similar conditions as those of Fig. 2A, but with two components,

15 CF_4 and SF_6 gas, added to chamber 102. The gas flow of SF_6 is 6 sccm. The volume ratio CF_4 : SF_6 in this experiment is about 10:1. Because the amount of CF_4 gas is greater than the amount of SF_6 gas, the CF_4 plasma is referred to as the dominant plasma and the SF_6 plasma is referred to as the secondary plasma. A trend line

20 304 shows that the etch rate becomes higher for locations farther away from the center portion of substrate 106. As an example, the etch rate at a location 85 mm away from the center is about 5% higher than the etch rate at the center of substrate 106.

Referring to Fig. 4, a graph 400 shows the experimental

25 results of etch rates when different amounts of SF_6 are added into chamber 102. A trend line 402 shows the etch rate distribution when SF_6 having a gas flow of 10 sccm is introduced

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into chamber 102. This corresponds to a volume ratio $CF_4:SF_6 = 6:1$. The trend line 304, as described above, shows the etch rate distribution when the gas flow of SF_6 is 6 sccm. A trend line 406 shows the etch rate distribution when SF_6 having a gas flow of 3

5   sccm is introduced into chamber 102. This corresponds to a volume ratio $CF_4:SF_6 = 20:1$. The trend line 204, as described before, shows the etch rate distribution when no SF_6 is added to chamber 102.

The graph 400 shows that when no SF_6 is added, the etch rate

10   at a peripheral portion is lower than the etch rate at the center of substrate 106, but as the amount of SF_6 relative to CF_4 increases, the etch rate at the peripheral portion increases. When a certain amount of SF_6 is added to chamber 102, the etch rate is substantially uniform across the wafer, regardless of the

15   distance from the center. The accuracy of etch rate is within about 1% across the wafer. The ratio of $CF4:SF_6$ is about 20:1 when uniform etch rate is achieved. The rate of etching is about 30 nm/min. Introducing a higher percentage of SF_6 to chamber 102 results in a higher etch rate at a peripheral location than at

20   the center.

The reactant gases which can be controlled to control etch rate include those that produce negative plasmas and those that produce positive plasmas. A gas produces a negative plasma when, under the pressure conditions of the chamber, it produces more

25   negative ions than electrons. A gas produces a positive plasma when, under the pressure conditions of the chamber, it produces more electrons than negative ions.

An example of a gas that can produce a negative plasma is SF_6, which typically produces a negative plasma at chamber pressure of about 60 mTorr or less. When SF_6 is used as the etchant gas, electrons collide with SF_6 to form SF_3^* and SF_5^*,

5 other sulfuric-fluoride ions, radicals, and more electrons: e + SF_6 => SF_3^* + SF_5^* + S_xF_y + e (x, y are an integer). An example of a gas that can produce a positive plasma is CF_4. When CF_4 is used as the etchant gas, electrons collide with CF_4 within chamber 102 to produce CF_3^* ions, other carbon-fluoride ions, radicals, and more

10 electrons: e + CF_4 => CF_3^* + C_xF_y + e (x, y are integers).

Referring to Figs. 5A and 5B, examples of the distributions of ions and electrons for CF_4 and SF_6 plasmas are illustrated. When CF_4 is energized into a plasma state, more electrons are generated than negative ions. Such plasma is referred to as a

15 positive plasma. Referring to Fig. 5B, when SF_6 is energized into a plasma state, more negative ions are generated than electrons. Such plasma is referred to as a negative plasma. (The percentage numbers in the figure are used only for purpose of illustration.)

Other gases which can produce a positive plasma include

20 other fluorocarbons, such as C_2F_6, C_4F_8, etc. Other gases which can produce negative plasmas include silicon fluoride and phosphorous fluoride. Oxygen can contribute to positive plasma at lower pressure but can be made more negative at a higher pressure. More than one type of gas may be used to contribute to either the

25 positive plasma or negative plasma. Other facilitator gases, such as N_2, Ar, and O_2 can be added to aid the processing. For example, O_2 is believed to etch by-product (polymer) clean so that

surfaces will not be covered to stop etching. Argon is for the same consideration, but Argon works through physical bombardment, while O_2 through chemical reaction. N_2 is used to improve selectivity and to reduce residence time of materials which need

5   to be pumped out.

For different dominant and secondary plasmas at normal operating conditions, or a different chamber pressure, or a different power for the radio frequency power supply, the etch rate distributions are different. By selecting an appropriate

10   amount of negative plasma and positive plasma, a desired etch rate distribution can be achieved, such as an etch rate that is substantially uniform across the wafer.

It is believed that the differences in the ratios of negative ions to electrons account for differences in spatial

15   distributions for CF_3^+, SF_3^+, and SF_5^+ ions within chamber 102, which affect the rate of etching across the wafer.

Referring to Figs. 2B and 3B, ion distribution simulations are provided under conditions similar to the experimental conditions of Figs. 2A and 3A, respectively. The simulations were

20   generated using PLASMATOR software, available through Lawrence Livermore National Laboratories and Kinema Research & Software, Monument, Colorado. In the simulations, CF_4 and SF_6 gases are simulated under conditions similar to operating processes. The CF_3^+ ion is the dominant species of etching in the CF_4 plasma, and

25   SF_3^+ and SF_5^+ ions are the dominant species of etching in the SF_6 plasma.

Referring to Fig. 2B, a graph 206 shows a simulation of CF_3^+ ion distribution within chamber 102 when only CF_4 is used as the process gas. The center portion of chamber 102 has a higher concentration of CF_3^+ ions than the peripheral portions of chamber

5 102. The higher concentration of positive ions results in a higher etching rate at the center portion of substrate 106 relative to the peripheral portions.

Referring to Fig. 3B, a graph 306 shows a simulation of SF_3^+ and SF_5^+ ion distribution within chamber 102 when only SF_6 is used

10 as the process gas. The SF_3^+ and SF_5^+ ions have higher concentrations at a peripheral portion of chamber 102 than at the center portion. The higher concentration of positive ions at the peripheral portion results in a higher etching rate at the peripheral portion of substrate 106 relative to the center.

15 Referring to Fig. 6, a graph 602 shows simulation results of SF_3^+, SF_5^+, and CF_3^+ ion density distributions along a radial direction from the wafer center, where the process conditions are identical as in Figs. 2B and 3B, respectively. Because the densities of SF_3^+ and SF_5^+ ions increase at locations farther away

20 from the center, whereas the density of CF_3^+ ions decreases at locations farther away from the center, when SF_6 and CF_4 are both used as process gases, the two types of ions complement each other and result in an even distribution of ion densities across the wafer. Such uniform distribution of positive ion densities

25 result in a uniform etch rate across the wafer.

An advantage is that uniform etch depths across a wafer substrate can be obtained, even without the use of a stop layer

(although a stop layer may be used as well). As a result, wafer processing may be simplified and the etching time may be reduced. The process can also be used to etch other substrates. An example is a quartz lithography mask, which is illuminated to generate a

5   lithographic interference pattern. The mask carries pits which are of uniform depth to maintain the accuracy of the out-of-phase interference relationship between light waves passing through the etched portions and light waves passing through the un-etched portions. Since the quartz substrate itself is being etched, a

10   stop layer is not used inside the quartz substrate to prevent non-uniform etch depth. In addition to uniform depths across a substrate, carefully controlled non-uniform depths can be achieved when desired.

Controlling the relative amounts of two types of plasma in a

15   chamber to control uniformity of etch rates across a substrate can be applied in different operation conditions where etch rates are different. For example, the method described can be used in silicon processes that need high etch rate to obtain high throughput. The method can also be used in photolithographic mask

20   processes where lower etch rates are preferred to simplify tool cooling systems.

Other embodiments are within the following claims.